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BUILDING TECHNOLOGY PROJECT SUMMARIES

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Editors
Noel Raufaste
Michael Olmert

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
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FOREWORD

The mission of the Center for Building Technology (CBT) is to increase the usefulness, safety, and economy of buildings through the advancement of building technology and its application to the improvement of building practice. CBT's research activities support the building technology programs of Federal, State, and local governments; assist the design professions, building officials, and the research community by developing improved design criteria; and assist manufacturers of building products by developing methods for evaluating innovative materials, components, and systems.

CBT's programs address building construction productivity, structural and geotechnical engineering, building materials, building physics, and building equipment. Typical CBT activities include: investigating failures, such as the Kansas City Hyatt Regency Hotel skywalk collapse, to determine needs for improved design and construction practices; improving measurement techniques, such as development and calibration of a hot-box to accurately determine heat transfer in full-scale complex-work assemblies; defining characteristics of building performance, such as predicting service-life of polymers (a group of materials expected to see much more use during the 21st century); and developing methods to predict the energy performance of new refrigerant mixtures for heat pumps. All these activities are conducted in cooperation with other organizations in the building community that participate in the studies or are affected by the results.

CBT does not promulgate building codes or standards. CBT provides an objective source of technical information for national consensus standards and model code organizations. Close cooperation with these groups leads to standard practices that meet the needs of the regulatory authorities of State and local governments. Research providing the knowledge for these standard practices is conducted in cooperation with Government, university, and industry laboratories.

This report summarizes CBT's research for 1981-1982. Each summary lists the project title, its progress, point of contact within CBT, and sponsor.

The summaries are arranged according to the research areas that comprise the scope of work at CBT. The report has a Building Community Index (last section), which keys CBT research to individual segments of the industry.

The reader is encouraged to review two companion documents: NBS Special Publication 439-1, *The Center for Building Technology: A Perspective*, which presents the Center's approach to building research and its facilities; and NBS Special Publication 457, *Building Technology Publications*, and its supplements. As they are produced, reports detailing results of the projects described here will be listed in future issues of *Building Technology Publications*.

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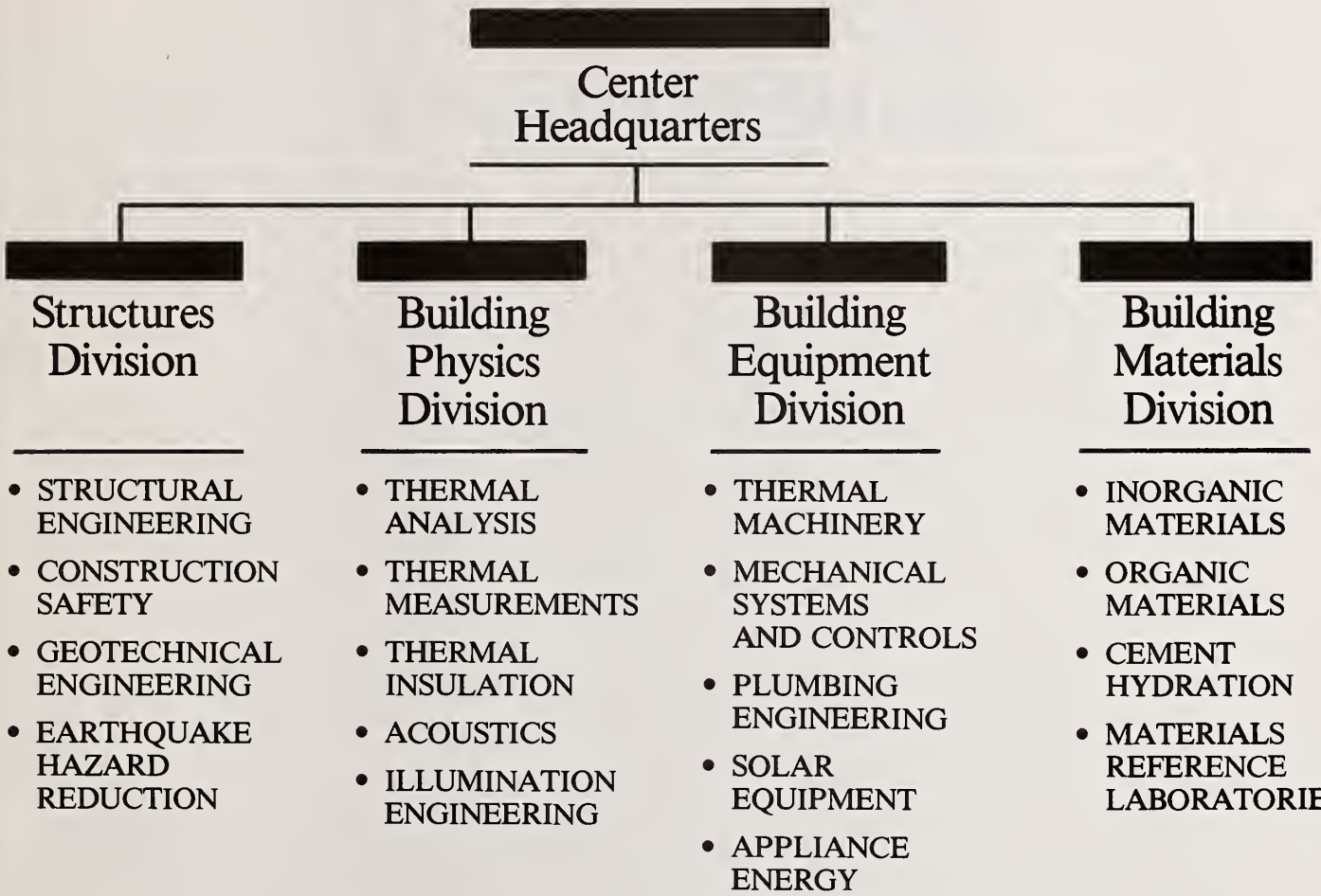
ABBREVIATIONS USED IN THE TEXT

AASHTO	American Association of State Highway and Transportation Officials
ABBE	Advisory Board on the Built Environment
ACF	Area Cost Factors
AID	Agency for International Development
ACI	American Concrete Institute
AIA	American Institute of Architects
AIARC	AIA Research Corporation
AMRL	AASHTO Materials Reference Laboratory
ANMC	American National Metric Council
ANSI	American National Standards Institute
ARI	American Research Institute
ASCE	American Society of Civil Engineers
ASPE	American Society of Plumbing Engineers
ASSE	American Society of Sanitary Engineers
ASTM	American Society for Testing and Materials
ASHRAE	American Society for Heating, Refrigerating, and Air-Conditioning Engineers
ASME	American Society for Mechanical Engineers
BECC	Building Energy Conservation Criteria
BFIRES	A Computer Program Dealing with Human Performance During Building Fires
BNL	Brookhaven National Laboratory
BOCA	Building Officials and Code Administrators International, Inc.
BUR	Built-up Roofing
CAD	Computer-Aided Design
CAM	Center for Applied Mathematics
CBT	Center for Building Technology
CERL	Construction Engineering Research Laboratory (U.S. Army)
CFR	Center for Fire Research
CIB	International Council for Building Research, Studies and Documentation
CICC	Construction Industries Coordinating Committee
CSA	Community Services Administration
CPSC	Consumer Product Safety Commission
DoD	Department of Defense
DoE	Department of Energy
EDA	Economic Development Administration
EIA	Energy Information Agency
EMCS	Energy Monitoring and Control Systems
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FCC	Federal Construction Council
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FmHA	Farmers Home Administration
FHWA	Federal Highway Administration
FIRL	Franklin Institute Research Laboratories
FPL	Forest Products Laboratory
GSA	General Services Administration
HHS	Department of Health and Human Services
HID	High Intensity Discharge
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air-Conditioning
ICBO	International Conference of Building Officials

IEEE	Institute of Electrical and Electronic Engineers
IERI	Illumination Engineering Research Institute
IES	Illumination Engineering Society
ISO	International Standards Organization
LBL	Lawrence Berkeley Laboratory
LNG	Liquid Natural Gas
MIMA	Mineral Insulation Manufacturers Association
MIUS	Modular Integrated Utility Systems
MPS	Minimum Property Standards
NAHP	National Association of Home Builders
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NBSLD	National Bureau of Standards Load Determination (A Computer Program)
NCSBCS	National Conference of States on Building Codes and Standards
NDE	Nondestructive Evaluation
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NIBS	National Institute of Building Sciences
NIOSH	National Institute of Occupational Safety and Health
NML	National Measurement Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	Nuclear Regulatory Commission
NRCC	National Research Council (Canada)
NSF	National Science Foundation
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PBS	Public Buildings Service
RCS	Residential Conservation Service
RIF	Resource Impact Factors
RILEM	International Union of Testing and Research Laboratories for Materials and Structures
RSV	Reduced-Size Venting
SAE	Society for Automotive Engineers
SERI	Solar Energy Research Institute
SPT	Standard Penetration Tests
SRM	Standard Reference Materials
TIFS	Thermal Indicating Flexible Strips
UF	Urea-Formaldehyde
USGS	United States Geological Survey
USNC/CIB	United States National Committee/International Council for Building Research, Studies, and Documentation
UV	Ultraviolet
VA	Veterans Administration

Center for Building Technology



STRUCTURAL ENGINEERING

Reliability-Based Design of Containments and Category I Structures

Bruce Ellingwood
(301) 921-2170
Structures Division

Sponsor: Brookhaven National Laboratory

The unpredictable nature of the possible loads on nuclear power structures, as well as uncertainties in structural properties and behavior, suggests a probabilistic approach for a rational assessment of structural safety and performance of structural design, this means that safety and performance should be determined according to acceptable levels of risk or required levels of reliability. In recent years, an increasing effort has been directed toward the application of reliability in structural engineering. Structural reliability theory has been applied to earthquake engineering, wind engineering, ocean engineering, aerospace structures, and in the development of load factors, load combinations, and resistance factors for practical design.

In the nuclear industry also, there has been an increasing trend toward the use of statistical analysis and probability theory for safety evaluations. This is particularly the case for seismic Category I structures for which rational methods for reliability evaluation of strength and loads are urgently needed. This new reliability-based design approach has a number of significant advantages. First, it encourages the designer to be more aware of safety and serviceability aspects of designs. Second, uniform load factors can be established that can be material-independent; and in addition, strength reduction factors can be established on the basis of material properties and structural functions. Finally, it is a tool for exercising judgment and provides a means for updating standards rationally. In certain instances, it could lead to more economical designs. It can be expected that structural designers will take advantage of these methods if they do not lead to significant additional complexities at the design level.

Under this joint project, BNL will have responsibility for analyzing accidental loads, postulating accident scenarios, dynamic structural analysis of the nuclear structures, and testing the design procedure. CBT will develop a statistical data base for service, environmental (dead, live, wind, snow, etc.), and extreme loads. Particular emphasis will be placed on a study of the temporal nature of individual loads since this determines their joint occurrence and other significant probabilistic characteristics.

Criteria for Structural Loads and Design

Bruce Ellingwood
(301) 921-2170
Structures Division

Sponsor: National Bureau of Standards

Current structural design standards rely on different philosophies and criteria for design, depending on the material or construction technology used. This tends to complicate design when different technologies are employed in the same structure. Differences in design philosophy cause a lack of consistency in the reliability levels of different buildings. In recognition of these problems, the trend in Europe and Canada has been toward the development of a common basis for design

that would be applicable to all buildings regardless of their material or construction technology. To ensure adequate performance, the unifying concept of limit states has been used, along with a probabilistic treatment of the uncertainties invariably found in engineering design. This project is concerned with the development of design criteria, specifically applicable to building standards in the United States, that will ensure adequate reliability against structural failure and unserviceability. This will lead to reduced building costs by simplifying the design process and stimulating market competition between construction technologies.

Criteria for Design of Cladding Subjected to Wind Loads

Emil Simiu
(301) 921-3169
Structures Division

Sponsor: National Bureau of Standards

Current design criteria for cladding subjected to wind loads are generally recognized to be seriously deficient. The lack of consistency in present criteria results in major economic losses and in major safety hazards. By contrast, uneconomical design of cladding is believed to occur in a large number of design situations. Modern analytical and experimental tools have not yet been used in investigating the reliability of cladding subjected to wind loads. Tools from the fields of wind engineering (aerodynamics of bluff bodies in turbulent boundary layer flows), nonlinear mechanics of plates, structural reliability, and materials testing will be used in this project with a view to developing rational criteria for cladding design. Data from full-scale and wind-tunnel investigations of wind loads on cladding will be reviewed and studies will be conducted to determine additional research needs.

Dependence of Extreme Wind Speed Upon Direction, and Its Effect Upon the Estimation of Design Loads

Emil Simiu
(301) 921-3169
Structures Division

Sponsor: National Science Foundation

Current U.S. procedures for estimating wind loads take into account the dependence of aerodynamic coefficients upon the direction of the wind speeds. However, no account is taken of the dependence upon direction of the extreme wind speeds expected to act on the structure during its lifetime. For this reason inherent in design wind loads estimated under current procedures are reliability levels that vary significantly among wind-sensitive components of the same structure. Under this project, a statistical procedure for estimating wind loads that may be expected to act on structures during their anticipated life will be developed, in which wind directionality effects will be taken into account. The procedure consists of creating scalar time series of the extreme wind pressures and inferring design wind speeds from the statistical analysis of such series. The procedure will then be adopted for use in hurricane-prone regions, where special statistical methods for describing the wind climate must be used.

Criteria for Wind Tunnel Modeling

Timothy A. Reinhold
(301) 921-2186
Structures Division

Sponsor: National Bureau of Standards

Although significant advances have been made in recent years, computational fluid mechanics as a practical and routine approach to the solution of wind engineering problems appears to be well into the future. Thus the low-speed, boundary-layer wind tunnel will, over the next several years, continue to be the primary tool for assessing the effects of wind on buildings and other structures. This project will support final design recommendations for a CBT boundary-layer wind tunnel. Facility design will be based in part on test data obtained from previous studies carried out on a 1/4-scale model of the proposed tunnel. This project also supported an international workshop, hosted by CBT, on wind tunnel modeling criteria and techniques. The workshop helped to define the state-of-the-art in wind tunnel testing for civil engineering applications and defined needs for future research.

Dynamics and Reliability of Compliant Drilling and Production Platforms

Emil Simiu
(301) 921-3169
Structures Division

Sponsor: United States Geological Survey

According to estimates published in the literature, costs of conventional fixed offshore platforms are prohibitive in deeper waters, where compliant structures become economically justified. These estimates indicate that guyed tower systems are economical for water depths within the approximate range of 1,000 to 1,600 ft, whereas the use of tension-leg platforms becomes economical for water depths in excess of about 1,600 ft. Because the behavior of compliant structures in a marine environment is complex, the evaluation of their performance can pose difficult problems to regulatory agencies. The purpose of this study is to create a basis for understanding the behavior of compliant structures and estimating their reliability during construction and service. The study will include the gathering and evaluation of information on proposed designs, identification of topics needing research, and research on critical topics.

GEOTECHNICAL ENGINEERING

Foundation and Excavation Standards

Felix Y. Yokel
(301) 921-2648
Structures Division

Sponsor: National Bureau of Standards

This project will assist ASCE in the development of national standards for foundations and excavations. Last year, draft standards were developed for pile foundations, pier foundations, shallow foundations, excavations, and explorations. Ballots were conducted for pile and pier foundations, and a committee reviewed shallow foundations. Working committees have been appointed for each of the areas and are now revising the standards, resolving negative ballots, and mediating between conflicting industry interests. The pile standard will probably be completed and re-balloted in FY81. It is also hoped that the pier standard can be re-drafted in FY82. CBT is aiding the five subcommittees in the preparation of the final standards and provides the secretariat for the committee work.

Geotechnical Measurements of In-Situ Soil Properties

William D. Kovacs
(301) 921-2885
Structures Division

Sponsor: National Bureau of Standards

The key to proper engineering design that can ensure the stability of structures, utilities, and construction sites lies in our ability to accurately characterize soil behavior. Since soil is not a man-made material, the key to its successful characterization lies in our ability to measure its properties in the undisturbed state in the ground. The state-of-the-art for in-situ measurement is in a constant state of flux, and research to improve, standardize, and assess these measurements is urgently needed.

One of the most widely used in-situ tests is the Standard Penetration Test. This test, as now performed, is poorly controlled and past CBT efforts concentrated on evaluation of current practice and improvement of the accuracy of the test. The CBT data are now being used in the revision of ASTM Standard B 1586 and some additional test parameters, particularly the effect of hammer/anvil geometry on energy loss are currently under study by CBT. CBT is also initiating research in a new area of in-situ measurement—in-situ characterization of soils by acoustic measurements. For this purpose, NBS, in cooperation with the Bureau of Reclamation, is building an acoustically-tipped cone penetration device that has the capability of measuring acoustic emission during the cone penetration and is also equipped with a hydrophone that can emit an acoustic signal. Actual field and laboratory work will begin in the summer of FY82.

In-Situ Measurement of Soil Properties by Thermal Methods

Lawrence A. Salomone
(301) 921-3128
Structures Division

Sponsor: National Bureau of Standards

The thermal conductivity of soil is significantly affected by soil moisture. The correlation between moisture content and thermal conductivity must be known for accurate predictions of energy dissipation of buried transmission lines and other structures surrounded by soils. Conversely, the correlation between moisture content and thermal conductivity may be used to measure soil moisture content in-situ and to determine the plastic limit of clays in the laboratory. Relatively little

information in this field is available and further exploration will lead to verification of these concepts and to entirely new approaches to the in-situ measurement of soil properties. As a result, this project will determine soil type, thermal conductivity, and moisture content on the soil around six test houses at the NBS NIKE site. The results will be used to validate the mathematical model used for predicting surrounding earth temperatures and floor heat-loss of the test houses. Also, measurement of thermal resistivity and its variation with moisture content will be performed on one type of clay from the American Association of State Highway and Transportation Officials materials reference laboratory. The results of these measurements will be correlated with the plastic limit of this clay.

Cyclic Strain Approach to the Determination of Liquefaction Potential of Level Sandy Sites

Riley M. Chung
(301) 921-2137
Structures Division

Sponsor: National Bureau of Standards

Relative density is currently used as the single important parameter in preparing laboratory specimens of sand to model liquefaction potential under in-situ conditions. Research now indicates that many other characteristics of the soil are important such as the manner of deposition, history of preconsolidation, and history of vibration. These are collectively referred to as the soil fabric. At present, two methods are used to predict liquefaction potential of sites. In the first method, Standard Penetration Test results from the site in question are compared with those from sites that liquefied in the past. In the second method, reconstituted samples are subjected to cyclic stress in the laboratory, using again Standard Penetration Test results to determine relative density in the field. In this project, a relationship between cyclic strain and pore water pressure buildup is established. Anticipated cyclic strain, in turn, can be estimated on the basis of the shear modulus of the deposit, which can be approximately determined from shear wave propagation velocities. A test series has been performed on Monteray #0 sand using cyclic triaxial and resonant column tests performed at CBT. These results established relationships for this particular sand. Effects of different soil fabrics and overconsolidation were also studied.

EARTHQUAKE ENGINEERING

Technical Assessment of Earthquake-Resistant Design Provisions

Edgar V. Leyendecker
(301) 921-3471
Structures Division

Sponsor: Federal Emergency Management Agency

This project will be a continuation of work with the Building Seismic Safety Council in its effort to support improved seismic design criteria. CBT will support the BSSC Committee, which is working on resolution of comments to proposed revisions to the Tentative Provisions for the Development of Seismic Regulations for Buildings. This will be done in coordination with other members of the Committee who will be voluntarily donating their time. CBT will also continue to participate on an ad hoc committee which is developing a plan for the conduct of trial designs to evaluate the provisions. To assure future use of the refined provisions, CBT will work closely with the Building Seismic Safety Council in all phases of the actual trial design process.

CBT will develop recommendations for future substantive improvements in Federal seismic provisions. The current draft is essentially based on current practice. It is the first step in improving Federal standards, with its primary purpose being the introduction of a uniform practice among all Federal agencies. Substantive improvements in the Federal seismic provisions for buildings will take several years to accomplish and should be coordinated with the eventual improvement in the private sector that will come about as a result of the BSSC activities. Working through the subcommittee on existing buildings, CBT will thoroughly review the present proposed guidelines for existing Federal buildings and develop suggested improvements. It is well recognized that hazards in buildings represent a large threat and that the problem is quite complex. CBT expertise in dealing with similar problems concerning the rehabilitation of old buildings and the application of retroactive building regulations will be brought to bear on this problem.

Seismic Limit-States for Structures

Edgar V. Leyendecker
(301) 921-3471
Structures Division

Sponsor: National Bureau of Standards

Standards for the design of structures are moving toward a reliability-based limit-states format. Current approaches to the specification of the limit-states for seismic resistant design have been to use the same limit-states used for gravity and wind loads. However, analysis indicates significantly lower levels of reliability for earthquake than for snow, wind, or live loads when using this approach. Such differences are likely to lead to unsafe or uneconomical standards for seismic resistant design or to delay the use of reliability-based limit-states approaches for the design of all loads. This project will improve the consistency of reliability-based design of structures through a clear identification of the design limit-states and the important response parameters.

Cyclic Loading of Masonry Building Components

Kyle Woodward
(301) 921-2885
Structures Division

Sponsor: National Bureau of Standards

The process of developing tentative seismic design provisions for both unreinforced and reinforced masonry building components reveals a scarcity of information on its ultimate strength characteristics. Since seismic resistance is now based primarily on ultimate strength considerations, the lack of such information for masonry building components is detrimental to its rational design in buildings subject to seismic loadings. This investigation will involve both experimental testing and analytical studies. Experimental tests will provide vitally needed information not now available that will be a resource to many investigators and will serve as the basis for development of mathematical models. A number of failure modes will be examined to identify the characteristics of each and the significant parameters affecting the different failure modes. Analytical expressions for predicting failure as a function of the key parameters will be developed. Later experimental testing will determine the generality of the proposed analytical expressions.

Review of LNG Facilities

Edgar V. Leyendecker
(301) 921-3471
Structures and Materials Division

Sponsor: Federal Energy Regulatory Commission

This study will review the structural design criteria of liquefied natural gas projects proposed for licensing by the Federal Energy Regulatory Commission (FERC). Although FERC does not have staff available, it is essential that appropriate evaluations be made of critical facilities such as LNG storage tanks. The review that CBT is to make will be used by the FERC in their overall evaluation for consideration of approval of construction. These reviews may involve work on state-of-the-art type problems that have broad application to many projects before the FERC.

One specific problem currently under review by the FERC staff is an application for use of a prestressed concrete tank at Staten Island, NY. But there is a problem with corrosion of some of its prestress wire. The FERC staff has a report submitted by the applicant on the extent of the corroded wire and the effect on the strength of the tank, which will be reviewed by CBT. Corrosion of prestress wire is a broad problem that has application beyond the specific problem at Staten Island.

CONSTRUCTION ENGINEERING

Construction Load Effects

H. S. Lew
(301) 921-2647
Structures Division

Sponsor: National Bureau of Standards

Compared with the provisions for occupancy design, current codes and standards provide little or no coverage on the design of buildings for construction. This is attributed to a lack of substantive information on construction loads and on the analytical tools needed for the evaluation of their effect on the partially completed structure and the temporary support system. At the present time, the Equivalent Frame Method prescribed by the ACI 318 Code allows the two-dimensional representation of space structures for analysis. However, when floors are interconnected by shores as in construction, analysis of the structure using an Equivalent Frame Method gives inaccurate results. To achieve a reliable level of safety in the design of concrete structures during construction, there is a need for the appropriate load factors to be used in evaluation of construction load effects on the structure. Under this project, a valid analytical model for concrete buildings under construction will be formulated. The field data on construction loads obtained in FY80 and FY81 will serve as a guide in the formulation of the analytical model. Additional field surveys will be carried out to refine the analytical model. Time-lapse photographic equipment will be used in the field during load measurement periods to gather information on the construction activities and imposed loads. The time-lapse data will be analyzed in conjunction with measured loads to determine its feasibility in predicting construction loads.

In-Place Tests for Concrete Strength

Nicholas J. Carino
(301) 921-3128
Structures Division

Sponsor: National Bureau of Standards

Removal of concrete forms and supports before the concrete has gained sufficient strength has resulted in collapses of structures under construction. Such construction disasters can be prevented if in-place strength of concrete at early ages can be determined accurately. On the other hand, unnecessary delay in removal of formwork leads to reduced construction productivity. Two of the most promising in-place test methods are the maturity method and the pullout test. Work completed at NBS on the strength-maturity relation of isothermally cured mortar specimens has resulted in a systematic approach for selecting the maturity function which best reflects the combined effects of temperature and time on early age strength development. The new approach, which is based on the empirically observed kinetics of strength development, appears to eliminate a major deficiency of the maturity function currently used in U.S. practice, namely the effect of initial curing temperature. The proposed study will show whether the new approach is also valid under non-isothermal curing conditions, and determine whether the strength-maturity relations obtained with mortar specimens are correlated with those of concrete specimens.

Two large-scale model tests of the pullout test have been completed in which, for the first time, the internal strain distribution within the concrete has been measured. Based upon the resulting data, a conceptual model of the different stages leading to ultimate failure of the pullout insert has been developed. This model indicates the roles of mortar strength and aggregate interlock in the failure process. The proposed failure mechanism will be verified using further experimental and analytical studies. The results of additional physical tests, using standard-size inserts, will be used to quantify the effects of mortar strength and aggregate interlock on the pullout strength.

Behavior of Concrete in Cold Regions

H. S. Lew
(301) 921-2647
Structures Division

Sponsor: National Bureau of Standards

Rising costs of fossil fuels have made it economically feasible to pursue new sources in arctic regions that were previously considered impractical due to environmental conditions. Large-scale concrete structures have been proposed and built, such as offshore drilling platforms, floating storage units, and land-based facilities. The arctic offshore environment poses serious problems for concrete structures and their durability. To enhance the productivity of structures in cold regions, there must be an understanding of the behavior of concrete in these environments. This is the initial study in this area and the primary thrust will be to document the state-of-the-art of construction methods and durability of concrete structures in cold regions. This will be achieved by a comprehensive literature review and a survey of major groups involved in cold regions construction. Based on the literature study and the responses to the survey, areas of needed research will be identified and a research program will be developed.

Improving OSHA Standards for Safety In Concrete Construction

H. S. Lew
(301) 921-2647
Structures Division

Sponsor: Occupational Safety and Health Administration

In recent years there have been several catastrophic and fatal failures of concrete structures during construction. The principal causes of these accidents are failures of the formwork/shoring system or premature applications of construction loads to the young concrete. Often these failures can be traced to inadequate engineering attention to formwork design, vague and often conflicting existing standards, and poor field practices. The goal of this study is to develop technical bases for improving existing OSHA standards for concrete construction and to develop analytical tools to aid in formwork/shoring design. An analytical computer-based model will be verified by means of field measurement of construction load effects for typical construction schemes. The nondestructive evaluation for in-place strength of concrete will involve critical evaluation of existing methods in terms of their reliability in predicting in-place strength of concrete. Based on this evaluation together with available research data, a recommended practice for in-place strength testing will be developed.

Development of Safety-Net Standards for Construction

James H. Pielert
(301) 921-3146
Structures Division

Sponsor: Occupational Safety and Health Administration

Falls during construction are a principal source of worker casualties. Safety nets are used to impede falls in many situations where active fall-protection devices, such as guardrails and safety belts, are either impractical, as in congested work areas, or are ineffective due to the absence of an adequate mechanism of support. Currently, there is an inadequate technical basis for the application and performance testing of safety nets used in construction. The purpose of this study is to develop a research strategy for safety nets. The available technical information on safety nets, including test procedures followed by manufacturers and related U.S. and international standards, will be analyzed. This will be followed by a field study of typical installation to establish current trends in the use of safety nets. Actual measurements will be taken to identify the pertinent structural and geometric aspects of the various installations, including physical constraints of the work environment.

Japanese Research in Construction

H. S. Lew
(301) 921-2647
Structures and Materials Division

Sponsor: National Bureau of Standards

In recent years Japan has made significant advances in productivity in construction through their R&D efforts in areas such as construction methods, materials, and materials handling. Today, armed with advanced knowledge in construction technology, Japanese construction firms have made successful inroads into the international as well as the U.S. construction markets. Types of projects range from construction of off-shore platforms to large tunneling systems for sewer and water supplies.

Construction R&D in Japan is carried out at three levels: at large construction firms' laboratories, at government laboratories, and at university laboratories. The laboratories of large construction firms carry out a significant part of R&D, and most of their research results are kept as proprietary information. However, it would be valuable to learn the modus operandi of their R&D in construction, including the role of government and private laboratories, allocation of resources, and subjects of research. The goal of this study is to collect information on Japanese R&D in construction and present it in a report.

Representation and Analysis of Construction Standards and Specifications

Frederick I. Stahl
(301) 921-2140
Structures Division

Sponsor: National Bureau of Standards

Standards and specifications are primary control mechanisms in the building process. Most research related to standards is concerned with improving the performance of building products. This work, by contrast, is concerned with improving the organization, expression and interpretation of the information in the standards and specifications. Techniques for testing aspects of clarity, completeness, and consistency have been developed and tested in prior work, and the development of easily usable general purpose software

for systematic application of these techniques has been started. Final release of this software will benefit standards developing organizations and will allow the start of studies for applications of the techniques in computer-aided design.

Constraint Processing in Computer-Aided Design

Frederick I. Stahl
(301) 921-2140
Structures Division

Sponsor: National Bureau of Standards

Computer-aided design (CAD) is critical to the improvement of construction productivity. Computers have been used in a significant way to aid engineering analysis for many years, and are just now being used to aid in the production of project drawings. Most of the computational effort in computer-aided design is related to checking of building properties against design criteria. This is termed constraint processing. Much of the effort in developing computer-aided design programs is concerned with correct and efficient constraint processing. Automation of the formulation and processing of constraints will reduce the costs of development and use of CAD systems.

NCIC Construction Productivity Case Studies

James G. Gross
(301) 921-3447
CBT Headquarters

Sponsor: National Bureau of Standards

Department of Labor Statistics show construction productivity increasing from 1950 to 1967 at an average of 2 1/2 percent annually. From 1967 to 1979 it averaged a decrease of 2 percent annually. The decrease in construction productivity appears to be the major single industry contribution to the overall decline in U.S. productivity. To improve this situation, the National Construction Industry Council (NCIC), composed of 28 national trade associations and professional societies of the construction industry, requested the Department of Commerce to provide technical assistance to improve construction productivity. CBT is providing assistance in preparing case studies on improvements in construction techniques and management for reducing costs while maintaining or improving quality.

The case studies will be developed by NCIC with emphasis on onsite construction. The management technology and production technology of high-productivity firms will be studied in a general sense and as applied to specific construction projects. CBT will analyze the case study from technical, economic, and productivity viewpoints. During FY82, two pilot studies will be performed to evaluate and to refine the method. During FY83 several case studies will be performed.

SERVICE-LIFE PREDICTION

Stochastic Model for Prediction of Durability Performance

Jonathan W. Martin
(301) 921-3208
Building Materials Division

Sponsor: National Bureau of Standards

If the present rate of growth continues, polymers could emerge as a major group of building materials of the 21st century. Many technical barriers exist, however, which may slow this growth. One such technical barrier is the thermal and non-thermal degradation of polymers in service. The purpose of this research is to demonstrate prediction of service-life, using a reliability physics approach, for poly (methyl methacrylate) as an example of a polymer subjected to thermal and photolytic stresses. This is significant because no such prediction has yet been made for any polymeric building material. The expected end result of this analysis will be the prediction of the service life distributions for all temperature and irradiance levels.

Development of Tests for Predicting Adhesive Bond Durability

Jonathan W. Martin
(301) 921-3208
Building Materials Division

Sponsor: U.S. Army

All branches of the military use lightweight, air transportable, rigid structures which serve as combination shipping containers and shelters for many types of tactical and life-support services. The use of these shelters has increased rapidly in recent years and life-cycle costs have become a major consideration. The shelters are fabricated from either paper honeycomb core or foam plastic sandwich panels. While honeycomb panels have several potential advantages, field experience has shown many problems. Debonding of panel components, stemming from poor adhesive performance, is a frequently observed problem. To address poor adhesive performance, there is a need to develop improved accelerated tests and probabilistic models to aid in predicting service life. Under this project, the performance of composite panels will be studied under varying environmental conditions of temperature and moisture. The test panels and.test apparatus will be designed on the basis of a theoretical model of a tactical shelter roof using finite element analysis. A theoretical life distribution will be fit to the time-to-failure data and the parameters of the life distribution will be used in determining the time transformation function relating time-to-failure and thermal stress.

Short-Term Evaluation Procedures of Coatings for Steel

Jonathan W. Martin
(301) 921-3208
Building Materials Division

Sponsor: Federal Highway Administration

Each year State transportation bureaus spend hundreds of millions of dollars protecting, from corrosive environments, bridges and other steel components associated with highways. To a large extent, the magnitude of this expenditure is affected by coating durability, for coating durability dictates maintenance policy. Essential to the optimization of maintenance schedules is an estimate of coating performance or service life obtained from short-term tests and extrapolated to expected environmental and operating conditions. Obtaining service life data prior to large-scale

application of a coating is a difficult task. The difficulty arises from the large number of material and environmental stress variables.

Because of the enormous magnitude of research needed to fully satisfy these objectives for all coatings and all exposure environments, it is essential to narrow the focus of the initial research to include degradation caused by the combined efforts of temperature and moisture for selected coatings. While degradation may result from multiple factors (temperature, moisture, ultraviolet radiation, cyclic exposure, salt, pollutants, etc.), temperature and moisture are of primary importance for most coatings. Development of tests to reliably predict degradation from these two factors will help meet the most immediate needs and will lay the foundation for subsequent research involving other degradation factors.

Investigation of Corrosion of Aluminum Roofing

Robert G. Mathey
(301) 921-2629
Building Materials Division

Sponsor: Defense Logistics Agency

Over 730,000 square feet of aluminum standing-seam roofing is scheduled to be applied over built-up roofing that failed prematurely (by splitting) at the Defense Construction Supply Center, Columbus, OH. The built-up roofing was applied only 6 to 7 years ago. The aluminum standing-seam roofing is considered as experimental for this type of reroofing application because of the relatively low slope of the roofs. However, the spread of acid pollutants over many areas of the United States has increased during the last decade. The state of Ohio is located in the most severe region of the United States with regard to "acid rain." The average pH in this area based on annual precipitation is 4.2 to 4.4. Values of pH of about 4 can significantly accelerate the corrosion rate of aluminum. Exposure to this low value of pH may severely reduce the service life of aluminum roofing systems.

This project will monitor, test, and evaluate the corrosion of low-slope aluminum standing-seam roofing in an area exposed to severe "acid rain." Laboratory and field studies will be conducted to measure the extent of corrosion and the corrosion rate by means of microscopic examinations, mass loss, and electrical potential across samples. The evaluation of the corrosion will give information which will contribute to estimating the service life of the aluminum roofing. Available information regarding environmental conditions (Weather Bureau data) to which the aluminum roofing is exposed will be obtained and recorded. Measurements will be made periodically of the pH of the rain water on the roofing. In evaluating the performance of aluminum roofing, the environmental conditions will be considered.

Corrosion of Steel in Prestressed Concrete

James R. Clifton
(301) 921-3458
Building Materials Division

Sponsor: Department of State

On the basis of a proposal submitted to the U.S./Spain Advisory Commission for Technology and Scientific Research on September 23, 1977, a cooperative investigation between the Laboratorio Central de Estructuras y Materiales del Centro de Estudios y Experimentacio de Obras Publicas y Urbanismo (Spain) and CBT began in September 1978. The subject of the research was "Factors Affecting the Corrosion of Steel in Prestressed Concrete Structures" and the work was planned to extend over the 5-year period, 1978-1983. Prestressed concrete is a form of reinforced concrete which makes highly efficient use of concrete and steel but puts particularly severe demands on these materials. The use of prestressed concrete for building and other construction such as bridges and pipelines is important in both the United States and Spain, and its use is expected to grow. Although the problems encountered with the performance and durability of prestressed concrete in the two countries appear to be different, there is a common basis of need for technical knowledge about the problems. The purposes of this project are to develop an improved understanding of the factors affecting the corrosion of prestressing steel in concrete, and to contribute to the formation of a technical basis for making service life predictions.

Crack Initiation and Growth in Concrete

Larry Knab
(301) 921-3120
Building Materials Division

Sponsor: National Bureau of Standards

Improved understanding of the cracking mechanisms of concrete and the effects of environment on these mechanisms is needed for developing more reliable models for predicting the service lives of concrete. On a macroscopic level, there has been considerable research on the cracking of concrete and several attempts have been made to apply the fracture mechanics approach. It is now clear that the classical fracture mechanics approach, based on brittle fracture, does not give an accurate representation of cracking in concrete. A major obstacle in developing a more accurate representation of cracking in concrete is the lack of understanding of the effects of flaw size and environment on the initiation of cracking. The purpose of this project is to investigate the development and propagation of cracks in concrete and the effects of microstructural features and environment on cracking. Development of analytical models describing cracking processes will also be undertaken. In the first year the effects of pore size and bonding between aggregate and cement paste on cracking will be studied.

Cement Hydration

Geoffrey Frohnsdorff
(301) 921-3704
Building Materials Division

Sponsor: National Bureau of Standards

The objective of this project is to improve understanding of the physics and chemistry of cement hydration and the development of microstructure in pastes of portland and related cements and to demonstrate the understanding through development and validation of mathematical models based on probable physical and chemical mechanisms. The project is planned to extend over 5 years. The work began with studies of the hydration of various preparations of the most important solid phase in portland cements, tricalcium silicate, and is being extended to other cement phases and mixtures of phases. The work consists of developing fundamental mathematical models based on alternative conceptual models. The mathematical models are tested against experimental data and revised as needed. Several preparations of tricalcium silicate used as starting materials were obtained from other laboratories and some large single crystals were grown in our laboratory. The materials were characterized in terms of chemical composition, particle size and shape distribution, specific surface area, and crystallite size. The materials are reacted with water and solutions of ionic and non-ionic compounds to determine the effects of temperature, and water-solid and water-surface area ratios on the mechanisms and kinetics of the reactions. Techniques used in studying the mechanisms and kinetics, starting from the moment of mixing, are heat evolution, volume change, electrical conductivity, x-ray diffraction, differential scanning calorimetry, image analysis, and chemical analysis of the aqueous phase.

Fly Ash Use in Cement and Concrete Products

James R. Clifton
(301) 921-3458
Building Materials Division

Sponsor: National Bureau of Standards

The stockpiling and disposal of fly ash are becoming increasingly more objectionable and subject to governmental regulations because of their effect on the environment. Over 50 million tons of fly ash were generated in 1981. About 300 million tons of fly ash have already been stockpiled. Use of fly ash in cement, concrete, and related products can potentially consume large amounts of fly ash. At present, less than 7 million tons/year of fly ash are being used in cement and concrete products, whereas 20 million tons/year seems a realistic goal. The purpose of this project is to identify technical obstacles to the increased use of fly ash in cement and concrete products and to develop a research plan to overcome these obstacles. As the first task, existing and potential uses of fly ash in cement and concrete materials have been identified. At the same time, potential levels of fly ash use in blended cements, ready-mixed concrete, and precast concrete products have been estimated. This has been based largely on considerations of the match between the chemistry of fly ash and raw materials or ingredients of these construction materials, the effect of fly ash on product performance and durability, and the possibilities for

expanding fly ash use. In the second task, barriers posed by technical factors and codes and standards to the increased use of fly ash in concrete materials are being identified. Fundamental research needed to overcome these barriers will be outlined. This effort will address individually the construction materials identified, and initially will include both bituminous and lignite fly ashes.

Standards for High-Security Glazing Materials

James R. Clifton
(301) 921-3458
Building Materials Division

Sponsor: National Institute of Justice, Law Enforcement Standards Laboratory

Recent disturbances at correction facilities, particularly that at the New Mexico State Penitentiary, a maximum security prison, have resulted in extensive damage. The extent of the damage and security breaches clearly demonstrated the need for new materials performance standards for the design and construction of penal institutions. During the course of this 3-year project, performance test methods will be developed to evaluate the resistance of glazing materials to impact, ballistic penetration, thermal and chemical attack, and abrasion. In addition, test methods will be developed to determine the effects of weathering on the above properties of glazing materials and other important properties, such as light transmission. These test methods will be used in determining the performance and durability of candidate glazing materials. An important phase of this work will be to establish realistic threat levels. Based on the test results and threat levels, performance criteria will be developed to form the basis for standards covering glazing materials.

Modeling of Roofs with Sheet Membranes

Walter J. Rossiter
(301) 921-3109
Building Materials Division

Sponsor: National Bureau of Standards

Under this project, conceptual and mathematical models will be developed for roofs having sheet roofing membranes, with the aim being to determine the required performance levels for the sheet membranes. The three major elements of a roof, i.e., deck, thermal insulation, and membrane, and the interactions between them, will be represented in the models. The effects of movement of the deck and thermal insulation, nature of the bonding between the insulation and membrane, and environmental loads on the behavior of the membrane will be treated by the model. Movement of the deck and thermal insulation will be simulated by a finite element approach. Partial differential equations for momentum and energy transfer will be set up and initial and boundary conditions identified. Properties of a sheet membrane material which will be considered include the strain energy, modulus of elasticity, ultimate tensile strength, and elongation and coefficient of thermal expansion. The nonlinear stress-strain characteristics of sheet membranes

will also be considered. During this year, the important factors which need to be considered in the mathematical model will be identified, the process of developing the mathematical model will be outlined, and a mathematical model will be formulated. Simultaneously, a comprehensive long-range research plan for obtaining data needed to solve the model will be prepared.

Organic Coatings

Mary E. McKnight
(301) 921-2635
Building Materials Division

Sponsor: Tri-Services Committee

The annual cost of organic coatings in the United States exceeds $8 billion. Maintenance costs alone would be significantly reduced if better systems, including surface preparation, were available. In developing test methods and specifications, this project contributes directly to the improvement of the coatings technology used by the military and also contributes to improvement of the Nation's coatings technology through publications, specifications, and participation in ASTM activities. The performance and other characteristics of new organic coating systems will be investigated and test methods developed or modified to assay the performance of these materials. Research will be performed to develop improved field tests for coatings evaluation, study the degradation mechanisms of coatings on steel, and identify methods for overcoming the problems associated with efflorescence. Also, advisory and consultative services based upon laboratory and field tests will be performed.

Performance of Residential Siding

Robert G. Mathey
(301) 921-2629
Building Materials Division

Sponsor: Tri-Services Committee

The increasing use of residential siding materials, both in new construction and maintenance, has led to the need for performance criteria to aid in the selection of materials. Of particular interest are criteria addressing durability performance. The Department of Defense previously supported NBS research to develop interim performance criteria for sidings. These sidings have been exposed for over 10 years at CBT exposure sites. During FY81 the Tri-Service Committee supported a study at CBT to measure the performance characteristics of the exposed sidings. Laboratory measurements included the same evaluative tests used previously, e.g., color and gloss change, adhesion, abrasion resistance, and thickness of coating. The performance characteristics of the weathered sidings are being compared with the performance characteristics reported in NBS Report 10805, "Performance of Residential Siding Materials." This information will be used to confirm or modify the interim performance criteria. Laboratory tests will be conducted on repainting the weathered siding materials. Adhesion tests will be used to determine the compatibility of the coatings with the weathered substrates. Initial adhesion tests will be conducted 14 days after repainting and after the siding materials have been weathered for about 1 year. Criteria will be prepared for recoating siding materials.

Detection and Characterization of Blisters Under Protective Coatings

Mary McKnight
(301) 921-2635
Building Materials Division

Sponsor: National Bureau of Standards

Blistering is one of the principal factors causing the failure of paint films. During the past 2 years, CBT has developed preliminary conceptual and mathematical models for predicting blister formation and growth under protective coatings in the initial phase of work to model corrosion degradation. Research has also been performed to study, using microscopy, the formation and growth of blisters with one protective coating under a limited number of exposure conditions. The data from the initial research have led to a better understanding of the phenomena, a microscopic method for detecting blisters and observing incipient corrosion phenomena, and preliminary data to aid in validating the mathematical model. However, additional data are needed to validate the model for blister formation and growth to relate the processes of blister formation to corrosion phenomena. Thus, under this project, research will be performed to quantify the factors contributing to blister formation and corrosion, and to investigate the feasibility of using electrical and thermographic measurements as a means of detecting blister formation and incipient corrosion and measuring the rate of deterioration. Quantification of factors contributing to blister formation is essential to ensure validity of the blister model. The microscopic method previously used in CBT research will be used to aid in the quantification of these factors as well as to characterize, at the macrostructure level, the process of corrosion. In addition, new research, based upon electrical and thermographic techniques, will be carried out to develop methods for generating the rate data. This research offers promise for the development of a technical basis for new and improved tools and methods by which blister growth and corrosion phenomena can be measured and by which the performance of coatings can be evaluated.

Tri-Services Technical and Scientific Support

Robert G. Mathey
(301) 921-2629
Building Materials Division

Sponsor: Tri-Services Committee

This project will provide technical and scientific support and consultative services on building materials and systems as required by the Tri-Services. The work will include carrying out laboratory tests and evaluations in the solution of building problems and field investigations. Recommendations will be made on the selection of materials and systems and their application and performance. In the past, problem areas have covered plumbing, masonry, roofing, corrosion, mechanical systems, insulation, materials, and underground piping.

Security Barriers

James R. Clifton
(301) 921-3458
Building Materials Division

Sponsor: Defense Nuclear Agency

Previous work at NBS has demonstrated that man passage openings could be produced in security barriers in surprisingly short times using readily available portable equipment. The times have been short enough to require a reappraisal of the use of these barriers for specific physical security applications. These applications include storage of nuclear and conventional weapons, radioactive material, secret documents, and precious metals. Furthermore, it appears that the deterrent capabilities of many barriers which are currently accepted for security applications may provide little resistance to penetration by newly-developed attack equipment such as the rotohammer, ring saw, Jet-Ax, and burning bar.

Many of the existing security barriers were constructed over 20 years ago and some of them have deteriorated to an extent that they need to be repaired. In addition, retrofit measures are being considered to upgrade the penetration resistance of existing structures. It is necessary to determine the condition of the existing building materials to select the proper repair or retrofit method. The use of nondestructive evaluation methods for evaluating the condition of existing materials in security barriers will be explored in this project.

Solar Collector Durability and Reliability Test Program

David Waksman
(301) 921-3114
Building Materials Division

Sponsor: Department of Energy

The reliablity and long-term performance of solar collectors has not generally been demonstrated. Recent studies have indicated that significant changes in collector performance (greater than 10 percent) can occur as a result of exposure to "no flow" conditions for 3 to 9 weeks. Various component and materials tests have been proposed to evaluate the reliability/durability of solar collectors. However, these testing procedures have to be experimentally validated. This project is intended to provide a coordinated testing program that will result in establishing validated testing procedures to relate laboratory, accelerated field, simulated operational exposure, and actual field demonstration data for solar collectors used in building heating and cooling applications.

A review of existing and planned testing procedures useful in evaluating the reliability/durability of collector units and their materials has been conducted and a detailed program plan has been prepared. Laboratory and outdoor field exposure tests are being performed on solar collectors and their materials. The results of these tests are being correlated and compared with actual in-use performance. These field exposures are being conducted at a number of different sites to evaluate climatic effects. Test specimens representative of various collector types are being used.

Standards for Solar Absorptive Coatings

Larry W. Masters
(301) 921-3458
Building Materials Division

Sponsor: Department of Energy

While numerous standard test methods have been developed for coatings in building construction, the performance requirements involved in solar heating/cooling systems are quite different. For example, temperatures on the absorptive surface may reach 250 °C or greater, but standard test methods for coatings seldom involve temperatures as high as 100 °C. Standard test methods which can be used to evaluate absorptive coatings under conditions of use are urgently needed. The purpose of this project is to prepare draft standards for absorptive coatings. The standards will be based upon the results of laboratory studies to evaluate available materials according to the performance required of them in service. The draft standards will be submitted to ASTM for consideration as consensus standards.

Development of Mathematical Models for Polymeric Absorber Coatings

Larry W. Masters
(301) 921-3458
Building Materials Division

Sponsor: Department of Energy

While new standard test methods have been developed at ASTM for absorber coatings based upon previous research, the data from these methods are difficult to interpret in terms of lifetime. Research is needed to develop mathematical models to aid in assessing degradation of polymeric absorber coatings and to aid in interpreting data obtained from the newly developed standards. Laboratory and field data on the performance and durability of absorber coatings have been obtained and reported in NBSIR 81-2232. These data, as well as new experimental data, will be used in this project to develop mathematical models of the degradation of selected polymeric absorber materials.

Standards for Nonmetallic Containment Materials

Larry W. Masters
(301) 921-3458
Materials Division

Sponsor: Department of Energy

Materials that contain, transport, or store fluids in solar energy systems are called containment materials. Plastic containment materials are being used increasingly in solar collectors, solar ponds, tanks containing heated storage liquids, and piping. But numerous field problems have been reported with plastics. These problems stem primarily from the poor thermal and UV stability of some plastic materials.

Many standard methods are available to evaluate plastic materials. However, the performance requirements for containment materials in solar systems are not entirely covered by the existing test methods. Under this project, performance criteria, performance attributes, degradation factors and currently available tests will be identified. Tests will be assessed to determine if modifications are necessary to reflect in-use solar conditions. Laboratory and field studies will be performed to prepare definitive test standards. Draft standards will be prepared in conjunction with ASTM committees and submitted to ASTM for consideration as consensus standards.

Standards for Solar Cover Plates

David Waksman
(301) 921-3114
Building Materials Division

Sponsor: Department of Energy

Most solar collector designs incorporate a cover plate whose purpose is to transmit solar energy while protecting the inner areas of the collector from the exterior environment and reducing the heat loss. Any loss in the transmittance of solar energy through the cover plate results in a decrease in the efficiency of the entire solar heating and cooling system. The transmittance and other important properties of some cover plate materials are frequently deteriorated by sunlight and the temperatures encountered in solar collectors. Many standard test methods are available to evaluate materials such as glass and plastic. However, the performance requirements for cover plates of solar collectors are not entirely covered by test methods developed for applications other than solar.

Under this program, performance criteria, performance attributes, degradation factors and currently available tests were identified. Tests were assessed to determine if modifications are necessary to reflect in-use solar conditions. Laboratory and field studies are being performed to obtain data needed to prepare definitive test standards. Draft standards were prepared in conjunction with ASTM committees and submitted to ASTM for consideration as consensus standards. Last year, ASTM accepted E765 and E782, which were based upon this research, as consensus standards. Additional research will be performed to identify methods for early detection of degradation and to develop data needed for interpreting the results of short-term tests in terms of service life.

Standards for Phase-Change Storage Materials

Paul W. Brown
(301) 921-2993
Building Materials Division

Sponsor: Department of Energy

Phase-change materials provide energy storage in terms of latent as well as sensible heat. These materials offer significant potential advantages in the volume of storage required and the thermal losses from storage. Consequently, the use of phase-change materials is increasing as the solar industry searches for more effective storage media. Key problem areas relating to the use of phase-change storage materials involve encapsulation and durability. Examples include rupture of encapsulating materials due to mechanical incompatibility with phase-change materials, thermal or chemical degradation of phase-change and encapsulating materials, and crystallization and segregation of components of phase-change materials as a result of repeated cycling and chemical incompatibility between phase-change and encapsulating materials. These problems can best be addressed through the development of performance standards and accelerated tests to allow assessment of the long-term performance and durability of phase change storage materials.

Degradation of Heat Transfer Fluids in Solar Heating Systems

Walter J. Rossiter
(301) 921-3109
Building Materials Division

Sponsor: Department of Energy

One of the problems which may affect the durability of a significant number of solar collector systems relates to the lack of information on the rates of degradation of glycol-based antifreeze solutions. This is because the degradation of glycols generates acidic reaction products which cause accelerated collector system corrosion. Ethylene glycol and propylene glycol may degrade by two major mechanisms under the conditions in a collector system. These are thermal decomposition and oxidative decomposition. Preliminary work at CBT has indicated that ethylene glycol is thermally more stable than propylene glycol but oxidatively less stable under one set of experimental conditions. It has also been observed that the presence of certain metals catalyzes the oxidative decomposition of glycols. The degradation kinetics of these compounds will be investigated as functions of temperature, availability of oxygen, and the presence of metals. Methods of analysis including mass spectroscopy and ion chromatography have been developed.

Documentation of Materials Research Data and Activities

Larry W. Masters
(301) 921-3458
Building Materials Division

Sponsor: Department of Energy

Since 1975, ERDA and DoE have devoted considerable emphasis and resources to research and development activities pertaining to materials used in active solar heating and cooling systems. These activities need to be documented so that summary data and information (objectives, scope, results and conclusions, reports published) will be accessible to researchers, materials developers, and users. The information should be of considerable value and assistance to manufacturers and developers in their selection and use of newer materials for solar application. CBT, in cooperation with the other research facilities involved with materials research (i.e., SERI, NASA, LANL) will compile an annotated bibliography of research studies (1975-1981) related to active solar materials performance. The document will be organized by subject matter for ease of use. It is anticipated that a related effort will be undertaken by Los Alamos National Laboratory (LANL) for the compilation of data and information which has resulted from materials research at LANL and through materials R&D contracts monitored by LANL for DoE. The NBS and the LANL efforts will be coordinated and will result in either a joint publication or compatible and coordinated separate publications.

QUALITY ASSURANCE

Cement and Concrete Reference Laboratory (CCRL)

John R. Dise
(301) 921-3481
Building Materials Division

Sponsors: American Society for Testing and Materials, U.S. Army Corps of Engineers

Over $4 billion of hydraulic cements are produced in the United States each year. The value of the concrete construction in which these cements are used is estimated to be on the order of $20 billion. Because of the large amounts of money and critical construction materials involved, standardization of testing to enhance the reliability of quality assurance measurements is most important. The CCRL contributes to this standardization through on-site inspections of apparatus and procedures used in the testing of cements and concretes, the distribution of proficiency test samples, laboratory investigations of testing problems, and participation in the activities of standard development groups. This work is performed by ASTM Research Associates working under CBT supervision. Plans for FY82 envision the distribution of 250 pairs of portland cement reference samples, and 180 pairs of portland cement concrete reference samples two times each during the year, and 150 pairs of blended cement reference samples and 75 masonry cement reference samples once during the year. Inspections of 110 cement and 135 concrete testing laboratories in 200 separate installations will be performed. Significant contributions to the work of ASTM Committees C01.95, C09.03.01, C09.03.03, and C09.03.05 will be made.

AASHTO Materials Reference Laboratory (AMRL)

John R. Dise
(301) 921-3481
Building Materials Division

Sponsor: American Association of State Highway and Transportation Officials

Modern technology used in today's operations by transportation agencies make it absolutely necessary to obtain relible measurements. Given the current state-of-the-art, this is an essential part of the process for assuring the quality of materials and workmanship used in our national transportation system. AMRL's primary responsibility is to provide services that assist the transportation industry in obtaining this necessary reliability. Under this project, with the support of AASHTO Research Associates working under CBT supervision, services are provided on a voluntary basis to both public and private laboratories which serve the transportation industry. At present, attention is focused on the testing of soils and bituminous materials and the measurement of frictional properties of highways. Apparatus and procedures used in performing quality assurance tests are checked for conformance to applicable national standards during on-site inspections. Proficiency test samples are distributed at regular intervals to obtain information on laboratory performance. Laboratory investigations of testing problems are conducted. New information about methods of test evolving from these activities is brought to the attention of cognizant standards development groups at frequent intervals. Plans for FY82 envision the distribution of 125 pairs of asphalt reference samples three times during the year, 200 pairs of soil reference samples and 145 pairs of aggregate reference samples two times each during the year, and 90 pairs of bituminous concrete reference

samples once during the year. Inspections of 30 soils, 30 aggregates, and 30 bituminous testing facilities in primary transportation laboratories will be performed. A prescribed annual listing of comments on the AASHTO standards will be forwarded for consideration by appropriate technical sections of AASHTO.

NDE of Building Materials

James R. Clifton
(301) 921-3458
Building Materials Division

Sponsor: National Bureau of Standards

This project is a study of the existing and proposed methods for nondestructive evaluation of in-place building components and materials. The techniques are useful not only in day-to-day construction but also in rehabilitation of older housing stocks and evaluation of buildings after natural disasters such as hurricanes or earthquakes. The results of this project are being brought to the attention of material scientists and material engineers through workshops, presentations at national meetings, and publications. Its purpose is to develop a technical basis to assist in the selection of appropriate NDE methods.

Visual Acuity Requirements for NDE

Gary T. Yonemura
(301) 921-2680
Building Physics Division

Sponsor: Department of Defense

This project will develop visual acuity targets and measurement procedures that can be implemented by the Ophthalmology Departments of the Armed Services' Medical Corps. In radiography techniques in NDE the human eye is used to detect and quantify the magnitude of imperfections. Since the eye is the instrument in use, standardized visual tests are required to evaluate the performance of the human eye. Much is known about the visual processes, but the visual conditions, techniques, and information capacity required of the inspector, as specifically related to NDE, are not established. Discussions will be held with DoD personnel on types of tasks and levels of difficulty encountered in DoD's non-destructive testing programs. Based on the evaluation of the different types of acuity tests currently being used and microdensitometric measurements of sample radiographs, acuity targets and testing techniques will be recommended. The possibility of making revised visual acuity test charts available as NBS Standard Reference Materials (SRM) will be considered.

Monitoring the 1980 White House Restoration

Larry W. Masters
(301) 921-3458
Building Materials Division

Sponsor: U.S. National Park Service

The performance of the 1980 White House restoration will be monitored through quarterly inspections and supplemental guidance about the performance of coatings for the White House will be provided to the NPS inspectors, as needed. Inspection data and field test results will be compiled as appropriate. Guidelines will be developed for a periodic cleaning program in cooperation with the Chief Usher of the White House. Based upon the data compiled on the performance of the coatings and surface preparation techniques used in the 1980 restoration, technical portions of the guide

Field Adhesion Tester

James Seiler
(301) 921-2909
Building Materials Division

Sponsor: Tri-Services Building Materials Investigation Committee

Adhesion is an important performance characteristic of many building materials, e.g., paints, roofing, and wall coverings. Most field methods for adhesion measurement are restricted to spring-loaded devices which may have many problems for obtaining quantitative measurements. However, in FY81, CBT developed a pneumatic adhesion tester for use in measuring coatings adhesion in the field. This year, work will be carried out to gain additional data on variables such as type, bond thickness, and cure of adhesive and substrate thickness. These additional data will help ensure reliable and reproducible measurements.

Plan for Abatement of Asbestos in GSA High-Rise Buildings

James H. Pielert
(301) 921-3146
Structures Division

Sponsor: General Services Administration

The GSA Public Buildings Service (PBS) has noticed some deterioration of the sprayed-on asbestos fireproofing in its high-rise office buildings. Renovation work carried out in the floor/ceiling cavity, elevator shafts, and other areas can disrupt the asbestos and cause fibers to dislodge into the air. A plan is needed for PBS to determine the level of asbestos problems in nine GSA buildings across the country and to identify and recommend remedial actions. The plan will recommend methods for detailed investigations of the buildings, and outline recommended abatement techniques and procedures for establishing priorities to apply the techniques. Priorities will be established through a cost analysis of the various alternative solutions and will address building system considerations, occupancy type, and occupant relocation issues. This general problem is of broad national interest.

THERMAL PERFORMANCE MODELING

In-Situ Thermal Resistance Measurements

Douglas M. Burch
(301) 921-3754
Building Physics Division

Sponsor: Naval Civil Engineering Laboratory

Under this project, an improved spot-radiometer technique for measuring the in-situ thermal resistance of walls will be developed. This technique will use a high-resolution (±0.1 °F) spot radiometer as opposed to a low resolution instrument (±0.5 °F) to measure the temperature difference between the subject surface and the ambient air. This temperature difference is often quite small particularly for insulated walls. The incoming radiant energy to the subject surface (the mean radiant energy of the surrounding surfaces) will be measured with a precision infrared radiometer, thereby permitting the radiative portion of the overall surface heat-transfer coefficient to be precisely determined.

Using two commercially available high-resolution spot radiometers and the improved spot-radiometer technique, a series of in-situ field thermal resistance measurements will be carried out using the walls of six test buildings. The thermal resistance of these walls has previously been determined by the heat-flow-meter technique and the guarded-hot-box method. Measurements would be carried out over a broad range of outdoor temperatures and solar loading conditions at various times of the day including the night. The estimated thermal resistance determined using the spot-radiometer technique would be compared with the known thermal resistance of the walls, thereby permitting the accuracy of the technique to be assessed. A comprehensive mathematical error analysis will also be carried out.

In addition, a feasibility study will be carried out to determine whether a ground-surface temperature survey using a spot-radiometer can be used to detect defective pipe insulation for underground district heat distribution systems. Here the ground surface temperature above insulated and non-insulated pipes will be predicted using a mathematical model as a function of pipe depth, outdoor temperature, and wind speed. Based on the results of this analysis, criteria will be developed to permit defective pipe insulation to be distinguished from good pipe insulation.

Field Measurements of Wall Thermal Mass

Douglas M. Burch
(301) 921-3754
Building Physics Division

Sponsor: Department of Energy

Six 20-ft wide and 20-ft long, one-room test buildings have been constructed at the NBS Nike Site. All six test modules have the same floor plan, orientation, and other common features, but with differing wall constructions. During FY82, special-purpose thermographic and heat-flow meter measurements will be carried out to locate, identify, and estimate the magnitude of thermal anomalies in the building envelopes. In addition, special-purpose winter heating energy measurements will be carried out on the test buildings with polystyrene insulation placed over their slab-on-grade floors. A comparison of the different heating load correlations for the cases with and without floor insulation will permit the edge and center

losses for the slab floors to be assessed. These special-purpose measurements are essential to provide a convincing validation of the steady-state model.

Modeling of Building Thermal Defects

Richard A. Grot
(301) 921-3470
Building Physics Division

Sponsor: National Bureau of Standards

This project will determine the theoretical basis for the quantitative analysis of building defects using thermographic data. Transient models will be developed for each class of defect in the thermal envelope (voids, cracks, corners, thermal bypasses, moisture under solar loading, etc.) typically observed during the thermographic inspection of buildings. The models will be used with image processing equipment to generate theoretical thermograms of these defects under various transient conditions. Transfer functions representing the physical performance characteristics of the various types of thermographic equipment will be used with the theoretical thermograms to assess the ability of the equipment to observe and quantify the heat loss caused by a defect under transient conditions.

Multi-Room Thermal Modeling

George Walton
(301) 921-3633
Building Physics Division

Sponsor: National Bureau of Standards

This project will develop a comprehensive modeling technique for predicting simultaneous transfer of air, moisture, and heat in and through multi-room buildings. Although numerous building thermal modeling techniques and computer programs exist throughout the United States, none of them can handle the following processes simultaneously: envelope heat transfer, envelope air leakage, envelope solar heat gain, room-to-room heat transfer, room-to-room air and moisture transfer, intra-room air movement, energy consumption by the heating/cooling equipment, indoor comfort, and water vapor condensation and containment migration. Existing models are virtually single-room models and dynamic coupling between the heated/nonheated spaces and/or the cooled/noncooled spaces are ignored. Under this project, then, a comprehensive computer program package similar to BSS 69 (NBSLD) will be prepared. Also expected are several technical and scientific papers on room air convection and inter-room heat and mass transfer.

Revised Attic Ventilation Guidelines

Douglas M. Burch
(301) 921-3754
Building Physics Division

Sponsor: Department of Defense Tri-Services Committee

Current guidelines on the minimum amount of attic ventilation are based on the experience and knowledge of persons in the building industry; they were developed approximately 30 years ago when the ceilings of homes had very limited insulation. Due to the energy shortage, current recommendations on insulation levels require much larger thicknesses of ceiling insulation. Houses with heavily insulated ceilings will have colder attics, which will be more susceptible to condensation and require higher ventilation rates. A need exists for a

rigorous rationale for formulating revised guidelines for controlled attic condensation. This project would also resolve the issue as to whether a ceiling vapor barrier should be required.

Underground Heat Distribution Systems

Tamami Kusuda
(301) 921-3501
Building Physics Division

Sponsor: Department of Defense Tri-Services Committee

Many underground heat distribution systems in military installations are failing because of the corrosion of the conduit system that covers the thermal insulation around the carrier pipe. Since it is an extremely expensive proposition to replace the entire underground system, it is desirable to have an accurate and easy-to-use instrumentation system that will detect only the segments of the system that have failed. The failed segments would exhibit high heat loss resulting in excessive temperature rise in the region over the pipe. Although various temperature sensing techniques such as earth probe, infrared devices, and heat flux meters are available to detect excessive ground cover temperature, there is no reliable technique to quantify the heat loss from the segment that has failed.

A simple heat transfer theory exists to translate the ground temperature profile over the underground heat source if the thermal property of the earth and depth of the earth cover are known. It is proposed, therefore, to evaluate various instrumentation techniques to measure the thermal conductivity and temperature of the soil above the buried underground heat distribution system, coupled with the depth of the microwave-based depth finder. A new system may be designed, fabricated, and tested in the test bed in which the underground system of known heat loss is buried at different depths and in different types of soil.

Thermal Test Methods—Solar-Assisted Heat Pumps and Solar Cooling Components and Systems

Kent A. Reed
(301) 921-3465
Building Equipment Division

Sponsor: Department of Energy

Solar-assisted heat pumps and solar cooling equipment are available commercially, and many advanced designs are being developed in the Active Solar Heating and Cooling Research Program of DoE. Uniform test methods are needed by the solar research community for comparing various research concepts at the prototype stage and by voluntary consensus standards organizations for developing standards to test, evaluate, and rate commercial products. In other projects, CBT staff members have played key roles in the development of test methods and evaluation procedures for conventional thermal machinery and for solar collectors and solar domestic water heaters. This project brings together these previously separate efforts. The current test methods and evaluation procedures for unitary heat pumps and unitary distributed air conditioning equipment will be critically reviewed. Modifications will be proposed to handle solar-assisted heat pumps and solar

cooling equipment. The modifications must account properly for the variability of the solar source and the use of auxiliary energy.

Thermal Test Methods—Solar Collectors

John P. Jenkins
(301) 921-3620
Building Equipment Division

Sponsor: Department of Energy

ASHRAE Standard 93-77 was the first widely accepted test method for determining the thermal performance of solar collectors. The Standard is based in large part on testing procedures drafted by CBT staff. The Standard Project Committee formed to review ASHRAE Standard 93-77 for its normal 5-year update has voted to revise the Standard to incorporate the latest advances in solar collector testing. This project consists of a critical review of the DoE-sponsored solar collector activities of the last 5 years that have a bearing on the revision of the Standard. These activities include the DoE Collector Test Program, the CBT investigation of indoor test methods, the NBS Collector Durability and Reliability Program, and many projects at other government and university laboratories. The past work in collector test and evaluation will be documented and assessed. Recommendations for revision of ASHRAE Standard 93-77 will be made, and critical areas requiring research will be identified. A concurrent experimental task will address the experimental uncertainty of a within-lab test sequence, and the influence of low level or diffuse light conditions.

Thermal Performance Data Requirements

Kent A. Reed
(301) 921-3465
Building Equipment Division

Sponsor: Department of Energy

In FY76, CBT worked with ERDA (now part of DoE) and a Performance Evaluation Committee established by ERDA to develop thermal data requirements and performance evaluation procedures for the National Solar Heating and Cooling Demonstration Program. These requirements and procedures were published in NBSIR 76-1137, August 1976. Considerable experience has been gained in using the procedures in this report to evaluate systems in the Program. A number of the recommended techniques have been found to be deficient and other techniques, not recommended, have been found to be of value. Utilizing data and experience gained in the National Solar Heating and Cooling Demonstration Program and other related DoE, SERI, and NBS research activities, CBT will prepare a revised thermal data requirements and evaluation procedures document.

Solar Hot Water Test Program

A. Hunter Fanney
(301) 921-3620
Building Equipment Division

Sponsor: Department of Energy

Experimental and numerical studies of the thermal performance of solar domestic hot water systems are being conducted concurrently in CBT. The experimental studies are investigations of the applicability of the newly adopted ASHRAE Standard 95-1981 to various systems. Data from these and other experiments are being used in the numerical studies to establish a technical rationale for defining representative test data. Together with these data, the ASHRAE Standard can be used by the industry to test systems for the purpose of rating their thermal performance. This project extends previous CBT research that provided performance data for validating simplified design methods such as f-chart, and established the technical basis for the alternate test method prescribed in the ASHRAE Standard 95-1981. Solar domestic hot water systems whose long-term performance had been characterized in the previous work are now being subjected to short-term tests. Experiments will also be conducted on new, innovative systems such as freon-charged solar water heaters. The results will be published, and specific recommendations will be made to ASHRAE and the solar industry associations.

Interaction of Solar Collector Optics and Solar Radiation Distributions

Kent A. Reed
(301) 921-3465
Building Equipment Division

Sponsor: National Bureau of Standards

In this project, the interaction of solar collector optics and solar radiation distribution will be investigated analytically and numerically. A number of models for solar radiation distributions already exist in the meteorology community, while detailed ray-trace calculations of the optical response of various solar collectors are just becoming available. These data, especially the radiation models of Dave (IBM) and the ray-trace models of McIntire (Argonne) will serve as the basis for the present investigation. As the study progresses, this base may be augmented with specific radiation and performance data collected at the NBS test site for this purpose. A specific thrust will be an investigation of the degree of error likely to be incurred with different levels of detail in the models. The level of detail to be investigated ranges from a single diffuse sky modifier based on an isotropic diffuse radiation model, to a full convolution of the instantaneous radiation distribution over the collector's optical response function.

International Energy Agency Solar Program Support

Kent A. Reed
(301) 921-3465
Building Equipment Division

Sponsor: Department of Energy

CBT has a major role in the U.S. development of test methods for determining the performance of solar energy components and systems for the heating and cooling of buildings. DoE has requested that this expertise be used to contribute to the international cooperative research in collector test methods organized by the International Energy Agency as part of its Solar Heating and Cooling Research Program. Specific objectives of the IEA collector test task include improving our ability to

characterize the thermal performance of solar collectors, developing technqiues for predicting the service life of solar collectors, and, most recently, developing methods to demonstrate that installed solar water heaters are performing properly. CBT is contributing results from its own as well as other U.S. solar research efforts, and is facilitating the flow of technical information from abroad into the U.S. solar program.

Simplified Energy Calculation Procedures

Tamami Kusuda
(301) 921-3501
Building Physics Division

Sponsor: Department of Energy

The success of the buiding energy performance design guidelines hinges on the availability of accurate, yet easy-to-use, energy analysis procedures. Although DoE has identified the DOE-2 program as the standard benchmark energy analysis procedure, this particular program is not suitable for use by practicing engineers and energy officials, because of its complexity and its need for large computers. To improve energy performance it is necessary to have available the criteria for certifying commercially available energy analysis procedures, or even simplified manual energy analysis procedures, which would result in an annual energy consumption estimate compatible with that produced by a benchmark procedure such as DOE-2. This year, technical documents will be produced on the residential energy analysis program based on a variable balance point degree-day approach including program documentation, a user's manual for a hand-held computer, and field validation data for several residences.

Window Solar Film Study

Stephen J. Treado
(301) 921-2758
Building Physics Division

Sponsor: General Services Administration

Solar films have been shown to be effective in reducing solar energy transmission through windows, thereby reducing peak cooling loads in buildings during summer. However, the effect of solar films on annual cooling and heating loads, as well as annual building energy consumption, has not been evaluated. To examine the annual effects of solar films, their impact on heating and cooling loads during transition seasons and winter must be evaluated. Energy savings due to reduced summer cooling loads may be partially or completely offset by increased heating loads in winter due to a reduction in beneficial window heat gain. In addition, the energy needed to satisfy the heating and cooling loads is dependent upon the HVAC system configuration and performance, as well as occupant parameters. In this project, laboratory measurements will be made to determine window heat gain with six generic types of solar film vs. clear glass. The six types of solar film will include a wide range of reflectance and absorptance characteristics. Using DOE-2, Federal Building 10B will be modeled and building energy requirements calculated for each film type and six climatic zones.

Thermal Test Methods—Passive Components

Michael E. McCabe
(301) 921-2308
Building Physics Division

Sponsor: Department of Energy

Modular components based on passive solar principles and used for solar heating and cooling of buildings and for domestic water heating are currently being developed and marketed in increasing numbers. However, there are no standard test procedures for thermal performance rating of these components; thermal performance comparison and economic evaluation of these devices are therefore impossible.

This project will develop standard thermal test methods for performance rating of a range of passive solar components. To support field testing of passive solar components, a calorimetric test facility capable of testing passive solar components up to 1.22×2.03 m (4×6 ft 8 in) in size and up to 0.41 m (16 in) in thickness, has been constructed. The metering chamber provides a nearly constant temperature indoor environment 1/2 °C within the range of 16 to 27 °C (60 to 80 °F). Thermal performance test results obtained in the test facility for a range of test articles will be compared with test results from laboratory conditions (based on simulated sun, wind, and air temperatures). The comparison of test results will provide the basis for recommending the use of or modifications to existing laboratory test methods or for developing new methods. Findings will be published on recommended test procedures and will be distributed to researchers, manufacturers, test laboratories, and professional and technical societies.

Performance Data Requirements for Passive Solar Buildings

Thomas E. Richtmyer
(301) 921-2308
Buildings Physics Division

Sponsor: Department of Energy

A passive solar test facility has been constructed at the NBS Annex (Nike Site). The four-room building can be configured so different wall types, energy collection schemes, and room layouts can be studied. The facility is now configured with a Direct Gain Room, a Control Room (i.e., a room with no special features) to provide comparative data, and a room with a collection/storage wall (Trombe wall). Also, the fourth room contains data-acquisition equipment and a Component Testing Calorimeter. The data collected will help determine minimum data requirements and performance evaluation procedures for passive solar heating and cooling systems. NBS has already developed such a procedure, which was included in the National Plan for Passive/Hybrid Solar Heating and Cooling Systems. The test facility will be useful in assessing the adequacy of the present plan with possible revision if necessary. The second product is a data base that provides detailed measured performance factors for the various test rooms. This data base will be used to validate passive-system computer models and various design tools. The data will be available from the Solar Energy Research Institute (SERI).

Thermal Comfort Analysis in Passive Solar Buildings

Stanley T. Liu
(301) 921-2607
Building Physics Division

Sponsor: Department of Energy

Over the past several years, the use of solar energy for heating and cooling buildings by passive design has received increasing emphasis by the architectural and building community and the DoE. However, the acceptance and rapid growth in the number of passive buildings will depend to a large extent on occupant comfort. The inherent greater fluctuations of indoor air temperature, humidity, and mean radiant temperature require the determination of the degree of human thermal comfort in passive solar buildings.

The recently revised ASHRAE Standard 55-81, "Thermal Environmental Conditions for Human Occupancy," included adjustments for extending the comfort zone due to the effect of air movement. It also set limits on the nonuniformity of vertical temperature distribution, radiant asymmetry, and floor temperature. This project will analyze the thermal performance data and determine the degree of thermal comfort in actual passively cooled and heated buildings based on this revised industry standard. This will assist designers in the development of better design and control strategy for passive solar buildings.

THERMAL INSULATION

Thermal Analysis and Modeling

Brian G. Rennex
(301) 921-3195
Building Physics Division

Sponsor: National Bureau of Standards

The characterization of thick insulation material is intrinsically difficult because of the large scale of appropriate measuring apparatus. There is a real and longstanding technical need to produce a definitive error analysis of an absolute apparatus such as the NBS 1000-mm line-source guarded hot-plate (GHP). In addition, there are important research issues such as the "thickness effect" and internal air convection, which will be studied using the NBS GHP apparatus. This project will help answer these research questions.

Calibrated Hot-Box Installation and Measurement

Frank J. Powell
(301) 921-3501
Building Physics Division

Sponsor: Department of Energy

In the development of performance standards and specifications, the need for better technical data and improved test methods for building materials and envelope systems is critical. This activity is a key element in the DoC/DoE National Program for Building Thermal Envelope Systems and Insulating Materials. This year, the assembly of the calibrated hot-box will be completed and acceptance test will be conducted using test specimen walls constructed of material selected for the ASTM C-16.30 round robin wall testers. Further tests using these specimen walls will be made to provide calibration coefficients and data to develop a precision and accuracy assessment of the apparatus.

Innovative Thermal Research

Brian G. Rennex
(301) 921-3195
Building Physics Division

Sponsor: National Bureau of Standards

The national importance of energy conservation encourages an improved understanding of thermal phenomena in "real" building situations. A fertile area for new research is in dynamic thermal modeling. Progress in the development of test methods and standards in this area would be of considerable use to organizations such as ASTM. Under this project, the techniques of response factors and finite element modeling will be developed for use in the analysis of dynamic tests on the new NBS-calibrated hot-box. The possibility of a simple, parametrical "response factor" approach to model franking loss and complex-wall heat transfer will be investigated.

BUILDING ACOUSTICS

Acoustics Measurements in Rooms

Fred F. Rudder
(301) 921-3783
Building Physics Division

Sponsor: National Bureau of Standards

Using the NBS Semi-Reverberant Room, the acoustical energy flow and transmission within the room will be characterized for steady-state excitation of the room by a signal of known magnitude and for various amounts and distribution of calibrated samples of sound absorbing materials. Data thus obtained will be compared with geometrical solutions and to eigenfunction solution to wave theory to assess the limits of applicability of the geometrical relationships and develop theoretical predictions for semi-reverberant rooms that are usable in common practice. To study the acoustical energy flow in rooms, it will be necessary to develop a measurement method for determining the spatial distribution of acoustical intensity within the semi-reverberant rooms. This method will be based upon a two-microphone array system and digital signal processing computations such as Fast Fourier Transform (FFT) and cross-power spectral measurements. The development and calibration of the two-microphone array system will use the NBS anechoic chamber.

Sound Absorption Measurements

Simone L. Yaniv
(301) 921-3783
Building Physics Division

Sponsor: National Bureau of Standards

Using the NBS reverberation chamber, a new and simple method will be developed for directly measuring total sound absorption. This method will be based upon excitation of the reverberation chamber by a continuous signal of known magnitude that is modulated by an infrasonic frequency. This new method will not require measurement of reverberation time, and thus will overcome some of the ambiguity in the interpretation of irregular decay curves. Results obtained with this technique will be compared with results obtained using a new method, ensemble averaging, that is based upon reverberation time but uses sophisticated computational procedures useful for research purposes but too complicated for use in everyday practice. In addition, the work performed by CBT last year on the effect of geometry on sound absorption coefficients of materials, from which total sound absorption is computed, will be extended to include effects of material mounting. This could result in the development of methods for correcting for the variation in the apparent absorption coefficients among geometrical distributions of material.

Guidelines for Acoustical Design of Light-Frame Wood Structures

Simone L. Yaniv
(301) 921-3783
Building Physics Division

Sponsor: U.S. Forest Products Laboratory (FPL)

This research is based on FPL work in acoustical performance of light-frame structures. The work will be completed in two phases. One phase comprises a review and preparation of a draft final report on acoustical guidelines for light-frame structures. This effort is based on a FPL draft report. The second phase is a compilation of FPL data on the sound transmission loss of light-frame structures. This data base will be assembled in a format for use by the building industry. This effort will provide the building industry with the first concise design guidelines based on data compilation on light-frame construction.

LIGHTING TECHNOLOGY

Visual Environment

Gary T. Yonemura
(301) 921-2680
Building Physics Division

Sponsor: National Bureau of Standards

Laboratory research at CBT, first using grating patterns, and then employing printed matter (realistic tasks), indicates that when visual sensitivity is measured by conspicuity of details, the function relating luminance with contrast is different from that obtained when the visual task is threshold detection, the historical basis for currently recommended illumination levels. An apparatus to assess conspicuities of typical office tasks relative to a reference five-bar target will be constructed. A modified form of this device will be used to test the feasibility of equal conspicuity contours as a function of luminance, utilizing variance of response as the dependent variable.

Optimized Model for Brightness

Gerald L. Howett
(301) 921-2670
Building Physics Division

Sponsor: National Bureau of Standards

Several brightness models have been published by vision scientists to date. This year, a generalized model that includes all the published "linear" models as special cases will be formulated. Using CAM's most modern computer programs for multivariate optimization, the generalized model will be given numerical values that best predict the most extensive body of published data on brightness vs. luminance. In later years, the program will include: similar optimization of an existing nonlinear model; new experiments on brightness to provide critical data for refining the evolving best model; and construction of a prototype 3-channel photometer as a physical realization of the new formula.

Concepts of Photometric Procedures

A. Ted Hattenburg
(301) 921-2680
Building Physics Division

Sponsor: National Bureau of Standards

Building illumination practice has historically relied upon simplistic measurements of illumination levels, poorly defined reflectance values, and complex calculation schemes based upon inadequate data. But new requirements for more cost-effective, energy conserving illumination systems are creating a demand for more precise, valid physical measurement techniques to guide systems design, evaluate the effectiveness of prototype and installed lighting systems, and contribute to the physical basis of vision research. Under this project, development of the field contrast measurement system will be completed. Practical near-field photometry techniques will be developed in the laboratory, to permit accurate luminance distribution determinations for office-sized work-spaces. A chapter on photometric measurement concepts will be prepared for inclusion in the NBS Optical Radiation Manual in collaboration with the Radiometric Physics Division of NML. Methods for reflectance determinations of room enclosure materials will be investigated to contribute to second-generation design computations. The project's output will be a report on field contrast measurement and the Optical Radiation Manual chapter.

Chromatic Adaptation

Gerald L. Howett
(301) 921-2670
Building Physics Division

Sponsor: National Bureau of Standards

Traditional research in the area of chromatic adaptation has always shown that the human visual system recovers chromatic sensitivity in the course of a few seconds. All of these studies have used continuous energy spectra as the stimuli. Recent work has shown that, under high-efficacy illumination systems with discontinuous spectra, the effects on chromatic adaptation persist as long as 23 minutes, when workers have adapted to ordinary office illumination levels (60 ft-c) for 45 minutes. In general, high-efficacy illumination systems are line spectra [most of their energy is concentrated in narrow bands] as opposed to energy in all bands (typical of continuous spectra). If confirmed, these results may lead to a redefinition of many of the current theories of color vision. In turn, there are long-term implications for illumination systems design and worker productivity and satisfaction in working under high-efficacy lights. Under this project, extensive laboratory explorations of the persistence of chromatic adaptation will be conducted. The type of illumination system, illumination level, exposure time, and age of the observers will be major variables.

Daylighting Studies

Stephen J. Treado
(301) 921-2758
Building Physics Division

Sponsor: National Bureau of Standards

Daylight has been recognized as an effective means of reducing the amount of energy required for interior building illumination. To determine the impact of daylighting on total building energy performance, the effect of daylighting schemes on building space heating and cooling energy requirements must also be considered. CBT has developed a simplified computer routine to calculate interior illumination for incorporation in existing building energy analysis programs, so that the overall effect of daylighting on building energy performance can be efficiently and accurately analyzed. In past years, large amounts of data have been collected at the NBS Daylight Research Facility, including measurements of outdoor solar radiation, daylight illumination, sky luminance, indoor daylight illumination and window-associated solar heat gain. Additional measurements were made concerning the performance of window management systems and automatic lighting controls. These measurements have been used to validate the simplified daylight calculation routine and to correlate outdoor illumination levels with the concurrent levels of total and diffuse solar radiation. This year, the daylight prediction program will be restructured to evaluate the effects of skylights, innovative fenestration designs, or complex room/window configurations.

BUILDING THERMAL EQUIPMENT

Examination of Non-azeotropic Mixture Refrigerants for Heat Pumps

David A. Didion
(301) 921-2994
Building Equipment Division

Sponsor: Electric Power Research Institute

Conventional vapor-compression heat pumps employ single-component refrigerants or azeotropic mixtures (those which have a single boiling-condensing temperature-composition phase diagram) as their working fluid. The use of non-azeotropic mixtures as the working fluid appears to offer at least three potential energy performance advantages without major changes in the manufacturing process of existing heat pumps. These advantages are an improved capacity-to-power ratio, a reduction in irreversibilities in the heat exchangers, and an increase in capacity at lower evaporator temperatures. The quantification of each of these advantages can be estimated theoretically; however, the cost-effectiveness of the design changes can only be done by optimization studies by manufacturers who are thoroughly familiar with manufacturing costs. A tool for predicting the energy performance as well as the operating costs of a design is the simulation model being developed in this study.

Refrigerant Mixture Measurements in Two-Phase Flow

David A. Didion
(301) 921-2994
Building Equipment Division

Sponsor: National Bureau of Standards

The convective heat transfer coefficient is the single most important property for the design of heat exchangers. For those heat exchangers which have internal boiling or condensation coupled with forced convection (e.g., refrigerant systems, steam power systems, etc.), the complexity of flow conditions are such coefficient values are normally completely empirically based. Since this study focuses on binary mixtures which are non-azeotropic (different oiling/condensation points), the problem is complicated even further. In single component fluids it is typical to establish an empirically-based functional relationship between the convective heat transfer coefficient and the other transport properties (e.g., conductivity, viscosity, etc.) for a given range of flow patterns and thermodynamic conditions. Once these relationships are established for categories of fluids, it is possible to predict the heat transfer coefficient based on the measurements of the other transport properties which are significantly easier to make. In the area of non-azeotropic mixtures, virtually no such relationships among the transport properties exist.

The specific group of fluids that will be studied is that of fluorocarbons that are used or intended to be used as refrigerants. The apparent advantages of using non-azeotropic mixtures in refrigerant systems are improvement in efficiency, less environmental (ozone) impact, multi-level evaporators, and self-lubricating working fluids. The evaluation of any of these possible advantages entails an overall performance evaluation of the refrigerant system, which in turn, requires knowledge of the transport properties of the refrigerant.

Furnace and Boiler Test Procedures

Esher R. Kweller
(301) 921-2935
Building Equipment Division

Sponsor: Department of Energy

This project will provide industry, via DoE, with an equitable testing and rating procedure for determining the seasonal energy performance of central residential furnaces and boilers. The Energy Policy and Conservation Act (PL 94-193) and the National Energy Conservation Policy Act (PL 95-619) require the Department of Energy to prescribe test and rating procedures and minimum performance standards for various residential appliances, including furnaces and boilers. DoE has, since 1975, relied on CBT to assist in the development of these procedures. A draft test and rating document for furnaces and boilers was delivered to DoE in 1977. Final publication in the *Federal Register* was in May 1978. Since then, DoE has been interested in expanding the procedure to include new furnace designs coming on the market (i.e., condensing units) and adapting the test procedure to fit unusual designs (i.e., sealed combustion installations). During the course of this development, NBS has supported DoE in defending or modifying the procedure according to suggestions made by industry, who were concerned about every detail of the procedure since virtually every furnace or boiler model sold in the United States will have to be rated in accordance with this procedure.

In FY82, CBT will help DoE in addressing the technical substance of all received "petitions for waiver" and "petitions for rulemaking" regarding the test procedures for furnaces. In addition, CBT is needed to assist in the technical analysis of public hearing testimony and written comments received in response to a proposed furnace test procedure amendment to be published by DoE.

Water Heater Studies

James E. Harris
(301) 921-2935
Building Equipment Division

Sponsor: Department of Energy

The Energy Policy and Conservation Act (PL 94-193) has mandated that household appliances, including water heaters, be labeled for energy use using standardized testing methods. Thus, it is necessary to establish standard test procedures that allow the accurate determination of energy efficiency, are repeatable, and not burdensome to perform. The objectives of this project are to expand and/or modify the DoE water heater test procedures where required and to provide laboratory data, analyses, and recommendations related to the test procedure.

Refrigerators and Freezers Studies

Robert A. Wise
(301) 921-2935
Building Equipment Division

Sponsor: Department of Energy

The objectives of this project are to expand or modify the DoE test procedures for refrigerators and freezers where required and to provide laboratory data, analyses, and recommendations related to the new tests.

Technical Support to DoE

Esher R. Kweller
(301) 921-2935
Building Equipment Division

Sponsor: Department of Energy

The Energy Policy and Conservation Act provides for the granting of waivers from testing for products which cannot be tested in accordance with the currently prescribed DoE test procedure. For DoE to respond to petitions from manufacturers for waiver, DoE must first resolve the question of applicability of currently prescribed test procedures to the products in question and then decide if waivers are to be granted or if testing under present test procedures is in order. CBT will provide DoE with the technical bases to make such decisions.

MECHNICAL SYSTEMS AND CONTROLS

Systems and Controls Laboratory

George E. Kelly
(301) 921-2144
Building Equipment Division

Sponsor: National Bureau of Standards

The focus of this program will be developing mathematical models and measurement techniques for evaluating the performance of building systems and controls, encouraging energy conservation in buildings through improved control strategies and software, and developing specifications and guidelines for implementing and maintaining automated building management systems. This research effort will complement CBT's current DoE-sponsored research program aimed at documenting the energy saving potential of the most commonly employed HVAC control strategies, developing algorithms for building control systems, evaluating the reliability of automated building management systems, and studying the application of sensors in energy monitoring and control systems.

The program is divided into tasks which are to be performed in successive years. The modeling effort and the development of control strategies and algorithms will be carried out in parallel with the planning, designing, implementing, and debugging of the laboratory facility. After this has been completed, experimental research on strategies and algorithms will begin, followed by fundamental research on control theory. This year's effort will involve the installation of an HVAC Test Facility; the design of interfaces and signal conditioning devices; and the development of strategies, algorithms, and data analysis software. Preliminary research will also begin to verify and refine the systems and controls models, the control strategies, and the mathematical algorithms. The modeling effort to develop simulations for various control loops, control hardware, systems, and equipment will follow.

Controls Dynamic Modeling

George E. Kelly
(301) 921-2144
Building Equipment Division

Sponsor: U.S. Navy/Department of Energy

None of the building simulation programs (e.g., BLAST 2, DOE 2) in existence today account for HVAC control dynamics. As a result of this, there exists very little reliable data on the amount of energy waste in buildings due to control dynamics and absolutely no information on how to design and operate building control systems to optimize dynamic performance. This project will concentrate on developing simulation models which can be used to predict the dynamic, "minute-by-minute" performance of control systems for building air handlers and commercial boilers. This will cover controls for the most common types of HVAC systems and build upon on-going NBS research to develop simulation models for building equipment and systems. Research in future years will involve building dynamics, heating/cooling plant dynamics, and the simulation of the entire building/HVAC/control system.

Energy Monitoring and Control Systems Algorithms

William B. May
(301) 921-3839
Building Equipment Division

Sponsor: U.S. Navy

At the present time there are no standardized, nonproprietary EMCS application algorithms available for use by companies entering the building controls field. Many of these companies lack training and experience in HVAC systems, building controls, and algorithm development. As a result, the building owner or manager who purchases their system is often stuck with an EMC system that either doesn't work or only partially works.

To assure a minimum level of performance of EMC systems, CBT plans to develop public domain algorithms for HVAC/building applications. Work will concentrate on an algorithm package for the control of building air handlers, including direct digital control of valves and dampers, time of day start/stop, duty cycling, demand limiting, temperature reset, economizer cycle, alarm report, etc. In future years, this effort will be expanded to develop algorithms for the control of heating and cooling plants and for the integration of building services.

Energy Monitoring and Control Systems Measured Performance

C. Warren Hurley
(301) 921-3839
Building Equipment Division

Sponsor: U.S. Navy

This project will help the Navy in studying and improving the performance of EMC systems installed at naval facilities. Somewhere between 30 and 70 percent of the EMC systems installed in this country are unreliable. Although this is due to many factors, one of the most significant problems is lack of knowledge by field personnel on how to purchase, install, calibrate and maintain sensors and measurement instrumentation. The sensitivity of building energy savings to EMCS sensor and system accuracies will be investigated by studying two Navy buildings in the Norfolk, VA area. Experimental evaluation of selected sensors in these buildings will be combined with a system analysis to determine the actual energy savings attributable to implementing different control strategies with real EMC systems. The particular sensors, strategies, and types of analyses to be carried out will be mutually decided by CBT and the Navy.

Energy Analysis of Control Strategies

James Kao
(301) 921-3844
Building Equipment Division

Sponsor: Department of Energy

Currently, the only information available on the energy savings resulting from the use of different control strategies is that put out by large control manufacturers. A study is urgently needed to independently document the potential energy savings of different commonly used strategies. In FY81, CBT used the computer program BLAST 2 to evaluate control strategies for a variety of HVAC systems in a small office building and a large retail store in different regions of the country. Typical strategies studied were dry bulb economizer cycle, enthalpy economizer cycle, hot and cold deck temperature reset, zone control, floating space temperature, and scheduled setback. In FY82, this work

will be extended to cover control strategies for two additional building types. The building's performance will be simulated for several different types of HVAC systems and for seven different geographical locations, representing typical U.S. climatic regions. Two reports will be published documenting the energy saving potential of the most commonly employed control strategies for the two building types studied.

PLUMBING ENGINEERING

Solid Transport in Horizontal Drains

Bal M. Mahajan
(301) 921-3293
Building Equipment Division

Sponsor: National Bureau of Standards

Recent experimental studies at CBT and several foreign countries have enhanced the understanding of the mechanics of water flow-induced motion of solids in partially-filled pipes. These studies have also revealed the complexities of the mechanics of momentum exchange between the water and solid and the dissipation of flow energy. Formulation and selection of suitable momentum exchange and energy dissipation models are essential for developing techniques for predicting the transport of discrete solids in partially-filled pipes under all flow conditions. These models also will be the basis for the development of an overall dynamic model that simulates the hydraulic characteristics of complex plumbing systems. The results will permit the calculation of pipe sizes for wastewater flow sweeping requirements to transport the solids through horizontal drains.

Computational Methods for Sizing Reduced-Size Vents

Lawrence S. Galowin
(301) 921-3293
Building Equipment Division

Sponsor: Veterans Administration

This research involves laboratory experiments and theoretical analyses to develop air flow rate and pressure relations within the interconnected vent piping network at Veterans Administration Hospitals' plumbing systems. Laboratory tests were conducted to measure trap seal depletion with reduced-size vents to evaluate the dependency on waste loading patterns, pipe size, air flow rates, and pressure losses through the piping system. Two design methods were established for vent pipe network design for prescribed pressure variations. Computer-based numerical solutions were developed for simultaneous equations that simulated vent branches headers. Comparisons of experimental results with predictions for trap seal losses were in good agreement. Improvement in the design methods requires additional research to develop reliable pipe fitting loss coefficients as a function of (a) geometrical parameters for the unequal cross-sectional flow areas of branch connections; and (b) flow convergence at different pressure conditions.

Innovative Circulation Loop Drain and Vent Modification

Lawrence S. Galowin
(301) 921-3293
Building Equipment Division

Sponsor: National Bureau of Standards

Rehabilitating buildings frequently imposes great loads on the water supply and drainage systems. The vent piping in older buildings often is marginal when retrofitting under the current code requirements. To increase the capacity of the system, CBT conducted an experimental laboratory investigation of "circulation loop" venting modification. The experimental evaluations of the performance of the modified system were compared to a conventional system for a variety of wastewater-load conditions with various plumbing fixtures and multistory soil stack loads. The performance parameters considered were: evaluation of trap seal failures, backflow, and the siphonic action of the water closets. Also, the dynamic responses to pressure excursions and air flow rate distributions in the branches

were measured. Both systems were tested to the limiting condition for single-stack performance over a range of air flow variations into the soil and vent stack.
The "circulation loop" system was found to reduce the pressure differences in the upper portion of the soil stack, and to provide limited benefits in reducing trap seal failures and reduced failures of the siphonic action of the lower level water closets. With vent valves open, both conventional and modified loop systems provided satisfactory venting except at the highest ranges of test loading patterns.

Low-Flow Shower Head Test Methods

Lawrence S. Galowin
(301) 921-3293
Building Equipment Division

Sponsor: Department of Housing and Urban Development

A test method for the evaluation of low-flow restrictor shower heads was developed. Included were the design and construction of a water collection "sector rig" device for measuring spray distribution patterns. Laboratory instrumentation requirements, suitable for application to the apparatus and the procedures for testing, were established. The test method provided measures of the principal operating characteristics; i.e., pressure-flow rate dependency and the shower spray distribution. Experiments were conducted with a small number of shower heads to determine the suitability of the measurements for application in the proposed test method. The results obtained from the experiments validated the concept and the proposed test method for evaluating shower heads.

BUILDING COMMUNITY INDEX

BUILDING COMMUNITY INDEX

The following listing presents the CBT projects organized by their interest to segments of the building community. The projects are listed under the appropriate building community groups as noted below:

1: Owners, Occupants, Users
2: Developers and Contractors
3: Designers
4: Labor
5: Financial Organizations
6: Manufacturers and Suppliers
7: Regulators and Standards
8: Testing Laboratories
9: Educational Institutions and Research Organizations

	Owners, Occupants, Users	Developers and Contractors	Designers	Labor	Financial Organizations	Manufacturers and Suppliers	Regulators and Standards	Testing Laboratories	Educational Institutions and Research Organizations
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Dependence of Extreme Wind Speed Upon Direction, and Its Effect Upon the Estimation of Design Loads, p. 3			X			X	X	X	X
Criteria for Wind Tunnel Modeling, p. 4			X				X		X
Dynamics and Reliability of Compliant Drilling and Production Platforms, p. 4			X				X		X
GEOTECHNICAL ENGINEERING									
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Geotechnical Measurements of In-Situ Soil Properties, p. 6	X	X				X	X	X	
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Cyclic Strain Approach to the Determination of Liquefaction Potential of Level Sandy Sites, p. 7			X			X	X	X	X
EARTHQUAKE ENGINEERING									
Technical Assessment of Earthquake-Resistant Design Provisions, p. 10			X		X		X	X	X
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Cyclic Loading of Masonry Building Components, p. 11			X			X	X	X	X
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CONTRUCTION ENGINEERING									
Construction Load Effects, p. 14		X	X	X			X	X	X
In-Place Tests for Concrete Strength, p. 14			X			X	X	X	X
Behavior of Concrete in Cold Regions, p. 15			X	X		X	X	X	X
Improving OSHA Standards for Safety in Concrete Construction, p. 15			X	X			X	X	X
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Japanese Research in Construction, p. 16			X	X		X	X	X	X
Representation and Analysis of Construction Standards and Specifications, p. 16			X				X	X	X
Constraint Processing in Computer-Aided Design, p. 17			X				X	X	X
NCIC Productivity Case Studies, p. 17	X	X	X	X	X	X	X		X

	Owners, Occupants, Users	Developers and Contractors	Designers	Labor	Financial Organizations	Manufacturers and Suppliers	Regulators and Standards	Testing Laboratories	Educational Institutions and Research Organizations
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Development of Tests for Predicting Adhesive Bond Durability, p. 20		X			X	X	X	X	
Short-Term Evaluation Procedures of Coatings for Steel, p. 20		X			X	X	X	X	
Investigation of Corrosion of Aluminum Roofing, p. 21		X			X	X	X	X	
Corrosion of Steel in Prestressed Concrete, p. 33	X	X			X	X	X	X	
Crack Initiation and Growth in Concrete, p. 34		X			X	X	X	X	
Cement Hydration, p. 35	X	X			X	X	X	X	
Fly Ash Use in Cement and Concrete Products, p. 36	X	X			X	X	X	X	
Standards for High-Security Glazing Materials, p. 37		X			X	X	X	X	
Modeling of Roofs with Sheet Membranes, p. 38		X			X	X	X	X	
Organic Coatings, p. 39	X	X			X	X	X	X	
Performance of Residential Siding, p. 40	X	X	X		X	X	X	X	
Detection and Characterization of Blisters Under Protective Coatings, p. 41					X	X	X	X	
Tri-Services Technical and Scientific Support, p. 42		X			X	X	X	X	
Security Barriers, p. 43		X	X		X	X	X	X	
Solar Collector Durability and Reliability Test Program, p. 44	X	X	X		X	X	X	X	
Standards for Solar Absorptive Coatings, p. 45					X	X	X	X	
Development of Mathematical Models for Polymeric Absorber Coatings, p. 46		X			X	X	X	X	
Standards for NonMetallic Containment Materials, p. 47	X	X			X	X	X	X	
Standards for Solar Cover Plates, p. 48		X			X	X	X	X	
Standards for Phase-Change Storage Materials, p. 49		X			X	X	X	X	
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Thermal Test Methods—Solar Collectors, p. 68		X			X	X	X	X	
Thermal Performance Data Requirements, p. 69		X			X	X	X	X	
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	Owners, Occupants, Users	Developers and Contractors	Designers	Labor	Financial Organizations	Manufacturers and Suppliers	Regulators and Standards	Testing Laboratories	Educational Institutions and Research Organizations
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Solid Transport in Horizontal Drains, p. 106			X			X	X	X	X
Computational Methods for Sizing Reduced-Size Vents, p. 107			X			X	X	X	X
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Low-Flow Shower Head Test Methods, p. 63	X	X	X	X		X	X	X	X

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